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   Patents ADP number *(if you know it)* — 6297261002

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   LAUNCH ANALYSER WITH REAL-TIME ADAPTIVE CORRECTION

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LAUNCH ANALYSER WITH REAL-TIME ADAPTIVE CORRECTION

TECHNICAL FIELD

This invention relates to apparatus for measuring parameters relating to the motion of a moving article and, in particular, apparatus for measuring and recording the initial velocity and spin of a golf ball, soccer ball or similar object that is launched into flight from an initial resting spot by impact from a club or other implement, predicting from the initial velocity and spin data the subsequent carry and flight duration of the ball or struck object, measuring the carry and duration of the actual flight and using the measured carry and flight duration data to correct the launch measurements and flight prediction model calibration parameters.

BACKGROUND ART

Most contemporary commercial ball launch analysers use time-elapsed photography to record and analyse the initial velocity and/or spin of a ball. One or more cameras capture images of the ball at two or more instances in time after initial launch and the velocity and spin of the ball are calculated from the relative positions and orientations of the ball images at two known instants in time.

The velocity and spin sensing method as outlined above has been established practice for many years. US Pat. No. 4.063,259 issued in 1977 is one early prior art document describing the use of a still camera with electronically controlled shutter and two or more electronically controlled flash lamps, the above being arranged to obtain images of a ball at two instants of time shortly after impact to provide measurements of ball speed, launch angle and spin rate. More recently, prior art such as US Pat. No. 6,390,934 issued in 2002, describes the use of digital cameras and image processing software to automate and enhance the measurement of ball launch conditions.

An indirect way of measuring the spin magnitude and spin axis of a golf ball is disclosed in GB Pat. No. 2334781, granted in 2002, where only the ball velocity vectors are measured and the ball spin vectors are deduced from measurement of the club head velocity, its position and its orientation at impact.

Knowing the characteristics of a ball, its launch velocity and spin vectors (as measured by the above inventions) can be used to predict the ensuing flight carry and duration. However, the accuracy of such prediction is very prone to errors arising from inaccuracies in the flight model, inaccuracies in the launch measurements and variations in atmospheric conditions (e.g. wind speed, rain effects, temperature and pressure).

The present invention aims to provide improved methods of measuring ball launch parameters by additionally sensing the actual carry distance and deviation and the flight duration to correct the launch measurements and flight prediction model calibration parameters.

One purpose of using accurate carry data to correct inaccurate launch data is that it is desirable to know what caused the outcome of a golf shot (to gain insight into a golfer's technique). A second application for this system is to identify the launch source (or "tee off" position) of different balls landing nearly simultaneously in the same general vicinity. Such a scenario obtains in golf ranges (or "driving ranges") and a benefit of the present invention is that electronic means are provided to tell each of several golfers using a golf range facility the exact outcome of their individual shots (i.e. display of carry distance and deviation) without confusion from nearly similar shots by neighbouring users of the facility.

One possible means of achieving the measurement of actual carry distance and deviation and the flight duration is disclosed in FR Pat. No. 2664503, granted in 1993, which describes the use of geophones distributed around a reception area to sense the impact of the ball as it lands. Signals corresponding to the time of arrival of the impact vibration at proximate geophones are recorded and, by analysing the time differences in these signals at different geophones, the position and time of impact can be accurately measured.

According to a first aspect of the invention, there is provided apparatus for measuring parameters relating to the motion of a moving article, the apparatus comprising one or more light sources for providing light from at least one reflecting zone of known shape or pattern on the moving article and co-acting light sensors arranged to provide a signal when it is illuminated by said light, wherein at least one light source and co-acting light sensor subtend an angle of less than 5

degrees at the said reflecting zone and common parts of the fields of view of the light source and co-acting light sensor define at least one detection plane across the path of the reflecting zone and at least one of the light sensors is arranged to sense variations in the said signal when the reflecting zone intercepts a given detection plane wherever the reflecting zone intercepts the detection plane and light reflected by different parts of the said shape or pattern is detected as the reflecting zone passes through the detection plane, the arrangement being such that the position and orientation of the detection plane relative to a reference frame is known and the time dependent displacement of the reflecting zone normal to the detection plane and the orientation of the reflecting zone about an axis within that detection plane can be determined from said signal.

According to a further aspect of the invention, the apparatus is provided in combination with one or more articles the movement of which is to be sensed, the, or each of the articles being provided with a retroreflective zone and/or diffusely reflecting zone. The said retroreflective zone may be provided with special prism structures with biased and/or variable tilt axes in order to orientate the maximum reflectivity at an incidence angle other than 90 degrees and/or make the reflectivity more uniform over a range of incidence angles.

The article may comprise a golf ball and, according to a further aspect of the invention, there is provided a golf ball for use with the apparatus, the golf ball may be provided with at least one retroreflective zone with the remainder of the golf ball surface providing a diffusely reflective zone.

The article may comprise a golf club and, according to a further aspect of the invention, there is provided a golf club for use with the apparatus, the golf club being provided with at least one retroreflective region preferably on the clubhead and/or on the lower end of the shaft, above the clubhead.

According to a further aspect of the invention, the apparatus is provided in combination with additional sensing means to detect and measure a golf ball landing position following a golf shot and data comprising the carry distance, deviation and duration of flight of a first and subsequent shots are used to correct the ball launch calibration parameters and/or the ball flight model parameters, taking into account prevailing atmospheric conditions. The said sensing means may

be optical, airborne acoustic, electromagnetic, electro-mechanical, radio frequency or other means but in a preferred embodiment, the vibration created by the ball landing impact is detected by vibration sensing means and the position and time of impact is determined from signals generated in the said vibration sensing means. The vibration sensing means may be single devices, each attached to individual panels that vibrate on impact so as to indicate ball landing on the area of the panel and/or a distributed array of geophones to sense ground transmitted vibrations or the like.

According to a further aspect of the invention, golf ball launch data (comprising impact time, launch velocity vectors and launch spin vectors), predicted carry duration data, predicted distance data, predicted deviation data, actual carry duration data, actual distance data and actual deviation data are used to identify the carry and deviation of each of several golf shots occurring in time and range proximity.

Preferably, one or more light sources and co-acting light sensor subtend angles at the reflecting zone of less than 2 degrees worst case, or more preferably less than 1 degree worst case, but typically 0.5 degrees or less. In this context, worst case means the maximum subtended angle corresponding to the minimum expected distance between the reflecting zone and the apparatus.

For convenience, we adopt the following nomenclature:

'Detection plane' is abbreviated to DP;

The angle subtended at the reflecting zone between a light source and its co-acting light sensor is the 'observation angle';

A light source and its co-acting light sensor is a 'TXRX pair';

The separation between the active elements in a TXRX pair (measured normal to the DP) is the 'TXRX separation'; and

The axis co-linear with the centre of the light source and the centre of the light sensor in a TXRX pair is the TXRX axis.

One means of creating a DP is to arrange the active elements in a TXRX pair in close proximity (e.g. 2 to 5 millimetres apart, but not limited to this range) and some distance behind a slit aperture. The width of the slit aperture may nominally equal the TXRX separation, with the length

axis of the aperture perpendicular to the TXRX axis. Neglecting the finite size of the active areas in the TXRX pair and diffraction effects at the edges of the aperture, the width of the DP in this arrangement is nearly constant throughout the useful extent of the DP and is equal to the TXRX separation (typically 3 to 4 millimetres). This controlled width DP is advantageously used in conjunction with retroreflective reflecting zones that have much greater reflective efficiency than diffuse reflectors, with the efficiency increasing with smaller observation angles. This increased efficiency helps to compensate for spreading losses at increasing range (and thus decreasing observation angle). When the DP is not more than x millimetres in width (where x can be any number, but typically 3 to 4 millimetres), different features in the shape or pattern of the reflecting zone can be detected provided that these features are separated by at least x millimetres. By providing a line array of light sources and light sensors with adjacent elements in the array forming a TXRX pair and with the array axis normal to the length axis of the slit aperture, the position of the DP can be altered, depending on which TXRX pair is selected or made active. In this arrangement, each TXRX axis is co-linear with the said array axis.

A second means of creating a DP is to arrange that the TXRX axis is parallel to the length axis of the slit aperture. Provided the TXRX separation is small compared to the length of the slit aperture, the fields of view for the light source and light sensor are nearly identical. The DP thus formed comprises the common field of view. An advantage of this type of DP compared to the previously described DP is that more light is emitted into the DP and more light is reflected back from the DP because the entire field of view is used. However, the width of the DP increases with range as it spreads out into a wedge shaped volume. This can be corrected using a cylindrical lens, so that the DP is again of uniform thickness (equal to the width of the slit aperture) or nearly so. This method of forming the DP improves its sensitivity and operating range.

It is sometimes desirable to use a diffuse reflecting zone (e.g. one side of the surface of a golf ball). Because diffuse reflection is inefficient, the above second method of creating DP(s) is preferred for diffuse reflection. In this case it is sometimes advantageous to have larger TXRX separation (giving greater observation angles) to enhance diffuse reflection and suppress retroreflective reflection from the same reflecting zone.

Means can be provided to enhance the detection of a retroreflective reflecting zone in the presence of spectral reflection (e.g. reflection from polished parts of the moving article) by using a first light polarizing filter between a light source and a retroreflective reflecting zone and a second light filter polarized at 90 degrees to the first polarizing filter in the path of the received reflected light. In this respect, it is useful to use visible red light TXRX pairs, since suitable polarising filters are currently more readily available in this spectrum. Alternatively, infrared light can be used where red would otherwise be distracting to the user, or a mixture of red and infrared can be used to optimise overall measurement performance and user acceptance.

Preferred shapes for the reflecting zones have simple geometries such as circular, hemi-spherical (i.e. a golf ball surface), triangular or quadrilateral. However, any shape that can be defined mathematically may be used. The DP's are preferably arranged to traverse the path of a reflection zone at various positions along the path and at various angles thereto. As a reflection zone travels through the various DP's, data capture circuits record the corresponding time and amplitude response. These data are used to compute the speed, position and direction of the reflection zone and thus determine the ball and/or clubhead motion. A powerful technique for extracting accurate three-dimensional data of the motion of a reflecting zone as it passes through an array of DP's is the Levenberg-Marquardt method for non-linear estimation. This, and alternative estimation algorithms, require a fairly representative mathematical model of the measurement system and to this end it is advantageous that the reflecting zones have basic geometries that can be described in simple mathematical terms.

The light emission in a DP may be continuous or pulsed. In one preferred embodiment, low duty cycle pulsed emissions with a repetition frequency in the range 10 kHz to 100 kHz are used with measurements coinciding with each pulse. This corresponds to providing measurements of a clubhead and ball positions at intervals of a few millimetres to a fraction of a millimetre. (In a `full swing` golf shot the clubhead speed at impact is typically in the range 25 m/s to 55 m/s, and ball launch speeds are typically 30% to 60% greater). For applications where the movement of a golf putter is to be measured, the repetition frequency can be much lower (e.g. circa 1 kHz).

The invention will now be further described, merely by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a logic block diagram of a golf range facility according to the invention;

FIG. 2 is a side elevation view of ball launch measuring apparatus according to one embodiment of the invention depicting two possible ball launch scenarios;

FIG. 3 shows a time dependent waveform representing a sensor signal generated in the arrangement of FIG. 2;

FIG. 4 shows a view along arrow A1 in FIG. 2;

FIG. 5 shows time dependent waveforms of representing sensor signals generated in the arrangement of FIG. 4;

FIGS. 6(a) to 6(f) are schematic views of typical detection plane arrangements; bbb

FIGS. 7(a) and 7(b) are schematic views of a further detection plane arrangement incorporating a cylindrical lens;

FIG. 8 shows two schematic views of a golf ball with a spherically symmetric arrangement of retroreflective elements;

FIG. 9 is a top view of ball launch measuring apparatus according to a second embodiment of the invention where both the clubhead and golf ball are measured during impact;

FIG. 10 is a side view of the clubhead and golf ball of FIG. 9; and

FIG. 11 shows a plan view of a sub-array of geophones on a range outfield.

The block diagram of FIG. 1 outlines the top level system for a golf range facility according to one aspect of the invention where several golfers hit golf balls into the same general area and sensing means are provided to describe the outcome and identify the initial tee position of every shot. Blocks representing first, second and Nth golfers using the range are show at 1,2 and 3 respectively. The golfers launch golf balls downrange into the flight space 4 at random times and with random distances and direction. For the purpose of system analysis, the flight space 4 can be considered as a flight transfer function with parameters comprising earth's gravity, air temperature & pressure, wind speed & direction and other factors that can affect ball flight such as rain or snow. We assume that the balls land on horizontal, flat terrain, but significant departures from this that would affect the time of landing or distance/deviation of carry, can be built into the flight transfer function. Preferably, all the golf balls used in the facility are of similar construction with nominally equal weight and diameter (which is true by default for all standard golf balls), and of closely similar impact and aerodynamic properties, which again is easily achieved. Each golfer is provided with one launch analyser 5, 6 or 7 that measures the initial velocity and spin vectors of the balls they hit and the exact time of each impact. The data from all the launch analysers are transmitted to a central computer 8.

The distance, deviation and flight duration of each golf shot is predicted by the central computer 8. From these predictions (which require knowledge of the parameters for the flight space, the ball parameters and the ball launch conditions) every shot made by each golfer can be identified. In practice, it is very difficult to achieve the necessary degree of accuracy to reliably distinguish between two or more shots landing at nearly the same position and time using launch measurements alone and, undesirably, the displayed results can sometimes differ significantly from observed results. To overcome these problems a landing sensors network 12 is provided that accurately measures the actual landing position and the time of landing of each golf ball.

Data from the landing sensors network 12 is transmitted to the central computer 8 that then compares actual outcomes with predicted outcomes and performs a best fit between actual and predicted data so every actual outcome measured by the landing sensors network 12 is attributed to a specific golf shot measured by the individual launch analysers 5, 6 & 7. These actual outcomes are then transmitted to video display units 9, 10 & 11, which provide each golfer with a

display of their performance, including information such as the distance and deviation of their recent and previous shots and, if desired, detailed shot by shot measurements of swing parameters and statistical analysis of their overall performance.

The actual landing data is also used to apply corrections to the data generated in each of the launch analysers 5, 6 & 7 and to update the computer model parameters for the flight space transfer function (i.e. wind speed & direction, air temperature & pressure, etc.). The above corrections are generated using iterative algorithms that test where and how much correction is appropriate so after a few results from each launch analyser the predicted and actual data converge (to within very small tolerance). The correction process continues as long as golfers hit balls into the instrumented range and adapts to environmental changes on an hour-to-hour and day-to-day basis. The computer can also monitor long term calibration drift in each launch analyser and elements in the landing sensors network and apply appropriate correction or report that specific components of the facility require maintenance. Optionally, wind and air parameters can be measured by a local weather monitor 13 positioned downrange and transmitted to the central computer to assist the prediction process. By this means the results shown on the video display units 9, 10 & 11 reliably report the correct results corresponding to each golfer's actual shots, and with great precision.

In rare instances, two or even three balls will land together near the same spot and at almost the same time. When this occurs, there is significant probability that the matching process between actual and predicted outcomes will fail to make an absolute true match, but this is of no consequence since the balls in question have carried to virtually the same spot so the result of distance and deviation for each shot is virtually unaffected.

FIG. 2 shows one form of launch analyser according to the invention. A golf ball 21 rests on a rubber tee 22. The tee 22 is semi-permanently fixed to a playing surface or play-off mat 23. Other ball placement arrangements may be adopted. For example, the ball can be placed directly on a mat or on turf, provided that the placement spot is nominally on a known vertical axis in relation to the apparatus.

For convenience, reference axes X, Y and Z are shown in the drawings. The Z-axis is vertical and points upwards. The Y-axis is horizontal and points downrange (i.e. along the general line of flight of a golf shot). The X-axis is orthogonal to Y and Z and points in the general `heel-to-toe` direction of a clubhead at ball address.

The golf ball 21 is provided with a small retroreflective element 24 adhered to its surface. The area of the element is typically only one hundredth or so of the total ball surface area. For convenience, we refer to the retroreflective element hereinafter as the RE. The RE may be elongate and, prior to a golf shot, positioned at the top dead centre of the ball and aligned along the desired launch direction. Three DP's 25, 26 & 27 are disposed below the ball flight path. As a reflecting surface enters one or other of the DP's, an sensor signal is generated within the sensor enclosure 28. The magnitude of this signal is proportional to the amount of light reflected back to the sensor, which in turn depends on a number of factors including the reflectivity of the surface under the prevailing conditions, the angle of incidence, the range or distance of the reflecting surface to the sensor enclosure and the area of the reflecting surface within the DP. Note that the DP's 25, 26 & 27 are not 'planar' in the strict meaning but have finite thickness. In one preferred arrangement, the thickness of any DP is less than the length of a RE.

The balls are themselves diffusely reflective so a central circular area of a ball passing through a DP can be detected. Thus, three successive instants in time when the centre of a ball coincides with the true central plane in each of the DP's 25, 26 & 27 are detected. The time of impact may be sensed by a microphone or other means and, knowing the above successive instants in time and the positions and the orientations of the DP's 25, 26 & 27 relative to the tee 22, the speed and trajectory of a ball can be found.

After impact from a lofted club such as a driver or iron, the ball travels at high speed substantially along a desired azimuth direction and upwardly at an elevation angle imparted by the club loft. In addition to linear velocity, each ball has backspin due to oblique impact, which again is due to the club loft. As a ball flies up and away from its pre-impact resting position, it rotates backwards so the RE eventually enters the downward facing hemisphere of the golf ball. Because of backspin, the peripheral speed of a ball on its lower (downward facing) surface is greater than the ball

translational speed. It follows that the RE's (if facing more or less downwards) pass through DP's at greater speed than the corresponding ball centres. The arrangement is such that the RE's can be detected by at least one DP for the range of backspin rates that are to be encountered. (More than three DP's at different angles can be used to ensure correct operation.) As a RE passes through a DP, its position forward or backward from the ball centre can be detected and this can be converted to a measure of the angle of backspin rotation at the time the ball passes through the DP, which in turn gives an accurate measure of the backspin rate.

For simplicity of description, we show DP 25 angled at 45 degrees to the vertical and tilted towards the tee, DP 26 on the vertical and DP 27 angled at 45 degrees to the vertical and tilted away from the tee. In FIG. 2 we show two possible trajectories with corresponding balls 29 & 30 and RE's 31 & 32 respectively. Ball 29 exhibits high trajectory and high backspin, typical of a shot from a high-lofted iron club, and in FIG. 2 it has rotated through 240 degrees (2/3 revolution) when its centre coincides with DP 29. In this case, the centre of RE 31 (being typically 10 millimetres long) has already passed through DP 25 so the sensor signal waveform 40 (shown in FIG. 3) exhibits a high output portion 41 corresponding to the passage of RE 31 through DP 25 prior to the peak 42 of the base signal. The base signal is of lower amplitude than signal portion 41 as it corresponds to the passage of the diffusely reflecting surface of ball 29 passing through DP 25. Although the reflecting area of RE 31 is much less than the effective reflecting area of the ball, the much greater reflectivity of the retroreflective surface provides the higher strength signal. Note also that signal portion 41 magnitude varies throughout its duration, being lower in magnitude at the leading edge 43 compared to the falling edge 44. The reason for this is that, due to the curvature on the ball surface, the first end of RE 31 to enter DP 25 presents a high 'entrance angle' to the incident light beam forming DP 25, whereas the following end of RE 31 presents a much lower entrance angle. The reflectivity of retroreflective materials increase with lower entrance angles and lower observation angles.

In contrast to ball 29, ball 30 has low trajectory and relatively low backspin, typical of a higher velocity golf shot from a driver or other wood club, and rotates through 135 degrees (3/8 revolution) when its centre coincides with DP 27. In this case, the centre of RE 32 coincides with the centre of the ball at the moment that both pass through DP 27 so in the corresponding sensor

signal waveform (shown at 127 in FIG. 5) the high output portion 51 coincides with the peak of the base signal. Note that the peak of signal portion 51 is much flatter than signal portion 41 (in FIG. 3) because in this instance the entrance angle is zero at the centre of RE 32 and still small at both ends of RE 32.

FIG. 4 shows the view along arrow A1 in FIG. 2. This view is on the underside of ball 30 and parallel to DP 27. An additional DP 45 (not shown in FIG. 2) is rotated about the centre axis of DP 27 (i.e. the axis defined by; X = 0, Y = OY + Z, where OY is the offset between the tee 22 and DP's 25, 26 & 27, measured along the Y-axis). Similarly, additional (but not shown) DP's rotated about axes defined by; X = 0, Y = OY - Z; and X = 0, Y = OY are associated with DP's 25 and 26 respectively. These DP's rotated in the X = 0 plane are used to detect any off-centre deviation of the ball or RE.

We show in FIG. 4 that the centre 46 of ball 30 is slightly displaced from the X = 0 plane 47 in one direction and RE 32 is also displaced from this plane but in the opposite sense. This offset between ball centre and RE is due to a component of sidespin on the ball, which tilts the spin axis off the horizontal. The degree of this offset advantageously gives a measure of the sidespin on a ball, which is an essential parameter to determine deviation in ball flight. The manner that the above displacements from the X = 0 plane affects the sensor signal waveform 145 for DP 45 relative to the waveform 127 for DP 27 is shown in the traces of FIG. 5. In FIG. 5 the origin (t = 0) corresponds to the moment of ball 30 trajectory depicted in FIGS. 2 and 4. For waveform 127, the signal responses due to the ball surface reflection and the RE 32 reflection are symmetric about t = 0, indicating that the ball 30 and RE 32 are central in DP 27. For waveform 145, the base signal peak 48 is earlier than t = 0, whereas the RE 32 response portion 49 is delayed. These relative time shifts provide a measure of the sidespin magnitude and sense.

The qualitative features of the signal waveforms of FIGS. 3 and 5 are evident, but it is not so obvious how to extract precise data from such waveforms. The preferred method is to use a guess of the ball and RE motion and apply this to a mathematical model of the array of DP's and their response to reflections off a ball and off a RE. The main features of the waveforms allow an initial approximate guess of the ball velocity, trajectory and spin from which model data are

generated. The model data and real data are compared and the differences are used to obtain an improved guess (i.e. an improved estimate). We repeat this process until the model data converges to nearly the same as the real data. The above is a simplified description of well-known techniques in engineering generally known as non-linear minimisation or no-linear estimation. One preferred mathematical technique for solving the estimation is the Levenberg-Marquardt method.

To formulate the initial guess, the motion of a ball and its RE are broken down into component parts as follows. When no sidespin is present, the RE rotates about a horizontal axis normal to the line of flight and on a vertical circle of diameter equal to the ball diameter. Superimposed on this spin motion, the spin axis moves at virtually constant velocity along a line normal to the axis. With sidespin, the RE rotates about an axis at a slight tilt angle θ to the horizontal (rarely more than 20 degrees) and on a circle of diameter reduced by cos (θ) and again the spin axis moves at constant velocity along a line normal to the spin axis.

FIGS. 6(a) to 6(e) show various arrangements for forming DP's. In FIG. 6(a) a light source (TX) device 60 is separate from a light sensor (RX) device 61 by distance δ, which is preferably less than 5 millimetres. An optical shield 62 (which may also form an electrical shield) is placed between the two devices and a slit aperture 63, also of width δ, is placed in the field of operation of each device at distance L. The slit aperture 63 is elongate with its length axis normal to the page, so the arrangement forms a DP that is normal to the page. For simplicity, the active areas of each electro-optical device are assumed to be negligibly small so that light rays to or from these devices can be considered to be a point receptor and point source respectively. The light rays beyond the aperture 63 spread out in two wedge shaped volumes 64, 65 where the angle enclosed by each wedge is δ/L radians. A DP 66 is formed in the overlap between the two wedges and provided the width between the devices 60, 61 exactly equals the width of the aperture, the DP 66 has parallel sides and is of width δ. FIG. 6(b) shows the arrangement of FIG. 6(a) in a view normal to the plane of the DP 66, where the length axis of the slit aperture is in the plane of the paper. The DP spreads out in a wide arc, limited by the ends 68, 69 of the slit aperture. In practice, diffraction effects and finite size of the active areas in the devices 60, 61 shape the width profile of the DP 66,

but over a useful operating range the thickness is fairly uniform and can be fairly accurately defined for computer modelling purposes.

FIG. 6(c) shows how three DP's 70,71 & 72 (with centre planes normal to the page) are formed from one TXRX pair 73 and three slit apertures 74, 75 & 76. The widths of the slit apertures 74, 76 are slightly narrower than the width of aperture 75 to allow for the foreshortening of the TXRX separation when the operating region of the TXRX pair 73 is oblique. This reduces the quantity of transmitted and received light in DP's 70 & 72, but the relatively smaller observation angles partly compensate.

FIG. 6(d) shows how a line array comprising three light emitting devices 77, 78 & 79 and two light sensor devices 80 & 81 form four DP's 82, 83, 84 & 85. In this arrangement, the three light emitters 77, 78 & 79 operate in multiplex mode (i.e. they are switched on, one at a time in succession) so only one or two of the four DP's are operated simultaneously. This arrangement can be expanded to a greater or lesser number of DP's and is useful to scan a stationary RE to detect its exact position before it is set in motion.

FIGS. 6(e) and 6(f) show an alternative arrangement where a wider DP is preferable to detect a golf ball using diffuse reflection off most of the available surface on the golf ball. Here a light emitter device 86 and light sensor device 87 are placed on a line parallel to the length axis of a slit aperture 88. This provides a DP in wedge shape form with increasing width at increasing distance away from the devices 86,87 and thus allows a greater amount of light, compared to the constant width DP's of FIGS. 6(a) to 6(d), to illuminate and reflect back from the diffuse surface of a golf ball. In detecting the position of a golf ball, a narrow DP is not necessary and the width can advantageously increase to slightly less than the ball diameter. This still allows a true peak to form in the sensor signal, which is detectible and corresponds to the ball centre being aligned with the central plane of the DP. By increasing the TXRX separation the observation angle is increased, which makes this type of DP less responsive to RE reflections but does not reduce its response to diffuse reflection. It is thus possible to provide one light sensor device with two multiplexed co-acting light source devices; one closely adjacent and placed on a line normal to the slit aperture

axis for optimum RE response and resolution; and the other on a line parallel to the slit aperture and at greater separation for maximum 'whole ball' response and low RE response.

In FIGS. 7(a) and 7(b), a TXRX pair 90, a cylindrical lens 91 and a slit aperture 92 are arranged with the TXRX axis, the length axes of the lens, and the length axis of the slit aperture parallel and coplanar. The TXRX pair 90 is disposed on the principal focal line of the cylindrical lens such that parallel rays (show as dashed lines 93 in FIG. 7(a)) converge to a line focus on the TXRX axis. With this arrangement, a DP is formed with nominally uniform thickness 94 equal to the width of the slit aperture and with angular extent 95 determined by the length of the slit aperture and the distance of the TXRX pair behind the aperture. The advantage of this arrangement compared to that of FIG. 6 (a), is that the angular field of view 96 of the TXRX pair (behind the lens) is much wider, so more light is emitted out and reflected back. Thus, this arrangement has higher sensitivity and detection range.

In practice, it is difficult to ensure that the TXRX pair 90 is exactly placed on the principal focal line of the cylindrical lens 91. Small errors in positioning result in the DP either converging or diverging, so that the thickness reduces or increases slightly with increasing range. If necessary, this variation (which is a constant systematic error) can be measured during system calibration.

In FIG. 8 a golf ball 100 is provided with a spherically symmetric arrangement of RE's 101. Typically, each RE is inserted as a separate element within the area of one large dimple on the ball surface. The RE's may be small circular discs of micro-prism retroreflective material, or may be single-prism structures or the like. It is necessary that the means of attachment of the RE's onto the golf ball surface is robust and withstands the high impact forces and ball compression during a golf shot. Alternatively, retroreflective areas may be directly fabricated or painted on the surface of a golf ball and individual areas may occupy more than one dimple. In the arrangement depicted in FIG. 8, 12 RE's occupy spherically symmetrical positions on the facets a golf ball with a regular dodecahedron dimple pattern. By this means, at least one RE is always within 30 degrees of direct view from any direction and can be easily detected by a DP. The RE's provide suitable reference marks from which the spin rate and spin axis of the ball can be detected using an array of DP's. Advantageously, this arrangement can be used to measure the spin rate and

spin axis of the ball with any arbitrary initial orientation prior to impact. In alternative arrangements, 6 RE's may be positioned on the vertices of an octahedron pattern or 8 RE's on the facets of an octahedron or 20 RE's on the vertices of a dodecahedron or 20 RE's on the facets of an icosahedron and so on.

For optimum aerodynamic performance and conformance with the *Rules of Golf*, the dimple pattern on the surface of a golf ball must be spherically symmetric or very nearly so, with the surface pattern preferably repeating many times. For example a dodecahedron structure where the pattern repeats 12 times is superior to an octahedron structure where the pattern repeats only 8 times. However, in the dodecahedron structure exemplified in FIG. 8, the RE pattern in certain directions of view repeats for each 72 degrees of rotation. This can be disadvantageous as it is necessary to ensure that rotations that are more than 72 degrees or multiples of 72 degrees are correctly sensed. This can be arranged by ensuring that the DP's are sufficiently close across part of the ball trajectory to sense the highest expected rates of rotation with rotations of less than 72 degrees. Alternatively, the spherical symmetry of the RE pattern may be broken provided that the aerodynamic symmetry is maintained. To achieve this, the mechanical shape of an RE must closely emulate the shape and aerodynamic properties of other parts of the surface. If this can be achieved, the RE pattern can be asymmetric so that it only repeats for 180 or 360 degrees of revolution, but the surface pattern is aerodynamically symmetric.

The methods described above can equally well be applied to the scenario of a spot kick on a soccer ball or rugby ball to measure the resultant velocity and spin components. Since a soccer ball has much greater surface area than a golf ball, numerous RE's or larger, specially shaped RE's can be provided on the ball.

FIG. 9 is the plan view of an alternative ball launch analyser where the velocity vectors and certain orientations and positions of a club head 190 are sensed prior to impact with a golf ball 191 and only the velocity vectors of the ball are sensed. A sensor enclosure 192 has a DP window face 193 generally parallel but offset from the golf swing and ball trajectory paths and provides a number of DP's 194 crossing the path of the club head and golf ball in the pre-impact and post impact region of a golf shot. The DP's comprise a mixture of normal, angled, narrow width and

expanded width types to fully detect the approach direction (in azimuth and elevation), speed, dynamic loft and offset (in vertical and horizontal sense) of the club head 190 and the launch velocity vectors of the ball. This gives sufficient data to determine the spin vectors of the ball as well as its velocity vectors. From this, a prediction of the subsequent ball flight can be made. Errors in measurement will degrade the accuracy of the flight prediction, but these errors are mainly systematic, especially if known types of club and a known type of ball are used. It is thus possible to correct systematic errors by applying feedback of the actual flight outcome measured by accurate means.

FIG. 10 shows a side view of the club head 190 and ball 191 as 'seen' by the DP array. The motion of the club head is sensed by tracking a triangular RE 195 attached to the toe of the club head. The leading edge of RE 195 aligns with the face loft of the club head and the centre of the triangle is at a known position relative to the centre of mass (CM) of the club head. These features ensure that the dynamic loft and the "gear effect" offset at impact are sensed.

The contrast of the RE 195 against reflections from the body of the club head can be enhanced by using filters to polarise the transmitted light from each TXRX pair in one direction and a second filter (for each TXRX pair) to polarise the received light at 90 degrees to the emitted light. In general, it is preferred to use infrared TXRX pairs as these are invisible to the golfers, but other light wavelengths such as visible red light may be preferable since polarising filters are more readily at these wavelengths. If necessary, a mixture of light wavelengths can be used to eliminate visible disturbance prior to impact and enhance performance during the impact phase only. Also, the club head body can be sprayed with non-reflective coating prior to attaching its RE. The sensor system can also sense and correct for spurious reflections from unwanted external light sources by detecting ambient signal amplitude just before or after each (pulsed) light emission.

The apparatus of FIGS. 9 and 10 or the arrangement of FIG. 2 may also be used to predict ball flight in indoor or other sites where the flight is restricted to a few metres only. Typically the ball may be a standard golf ball or a light-weight practice ball hit into a barrier (such as a net, a fabric drape or semi-rigid means) that stops the ball shortly after launch and absorbs the ball kinetic

energy so that it drops downwards with very little or no bounce back off the said barrier. Advantageously, the barrier may be concave, at least on its lower part, and shaped so as to guide the ball into a sloping gutter or the like, along which the ball rolls back to a collection area adjacent to the tee or initial launch spot.

FIG. 11 shows part of a golf range outfield with four geophones 200, 201, 202 and 203 arranged on the corners of a square with sides **L** metres long. A golf ball lands at point 204, which in this arbitrary instance is closest to geophone 200, and the time taken for impact vibrations to travel from point 204 to geophone 200 is **T** seconds. Geophone 200 is taken as the origin of **X** and **Y** axes as shown. Thus, the landing point 204 is a distance **x** metres and **y** metres measured from geophone 200 (with **x** negative and **y** positive in the example of FIG. 11). For simplicity, we assume that the impact vibration propagates at constant velocity **V** metres per second along the ground surface and neglect sub-soil effects such as reflections off bedrock layers and multiple path propagation, etc. In order to calculate the position of the landing point 204 relative to the four geophones it is necessary to know the value of **T** and **V**. If we say that **t1, t2** and **t3** are the differences in times (in seconds) between the impact vibration being first sensed at geophone 200 and then being sensed at geophones 201, 202 and 203 respectively, the value of **T** is given by:

$$T = \frac{t2^2 - t1^2 - t3^2}{2(t1 + t3 - t2)} \qquad (1)$$

To find **V** it is preferable to have three co-linear geophones. For example in FIG. 11, a fifth geophone 205 is provided such that geophone 200 is co-linear to and equidistant from geophones 201 and 205 with separation distance **L** from each. With this arrangement, **V** can be found from:

$$V = \frac{L}{\sqrt{T(t1 + t4) + 0.5(t1^2 + t4^2)}} \qquad (2)$$

where **t4** seconds is the difference in time between the impact vibration being first sensed at geophone 200 and then being sensed at geophones 205.

It is not necessary to calculate **V** for each instance of a ball landing since it is a constant, or very nearly so. However, it is useful to measure this parameter as a check on data integrity and to monitor gradual changes due to changing ground conditions (e.g. moisture and temperature).

Having found **T** and **V**, the position of the landing point 204 can be found from:

$$x = \frac{L}{2} - \frac{(2T + t1)t1.V^2}{2L} \tag{3}$$

$$y = \frac{L}{2} - \frac{(2T + t3)t3.V^2}{2L} \tag{4}$$

The above equations are exemplary of exact expressions that locate the X and Y co-ordinates of a ball landing point. Other means may sometimes be required. For example, EQ. 1 is only valid provided that **t1** and **t3** are both non-zero. If **t1** or **t3** is zero, then the ball landing point is on a line of symmetry and the position of the landing point can be found by triangulation, provided that **V** is already known. If **t1** and **t3** are both zero, then the ball landing point is in the exact centre of the square.

In practice, **V** is accurately determined by calibration during initial commissioning of the overall range site. The actual times of arrival of impact vibrations to any geophone will not generally fit the simple model described above, but calibration will reveal how the actual vibration propagation differs from the model and correction factors can be applied. EQ. 2 is then useful to monitor gradual changes and predict corrections to the initial calibration. If they exist, variations in the value of **V** in different regions of the outfield can be mapped and held in computer memory.

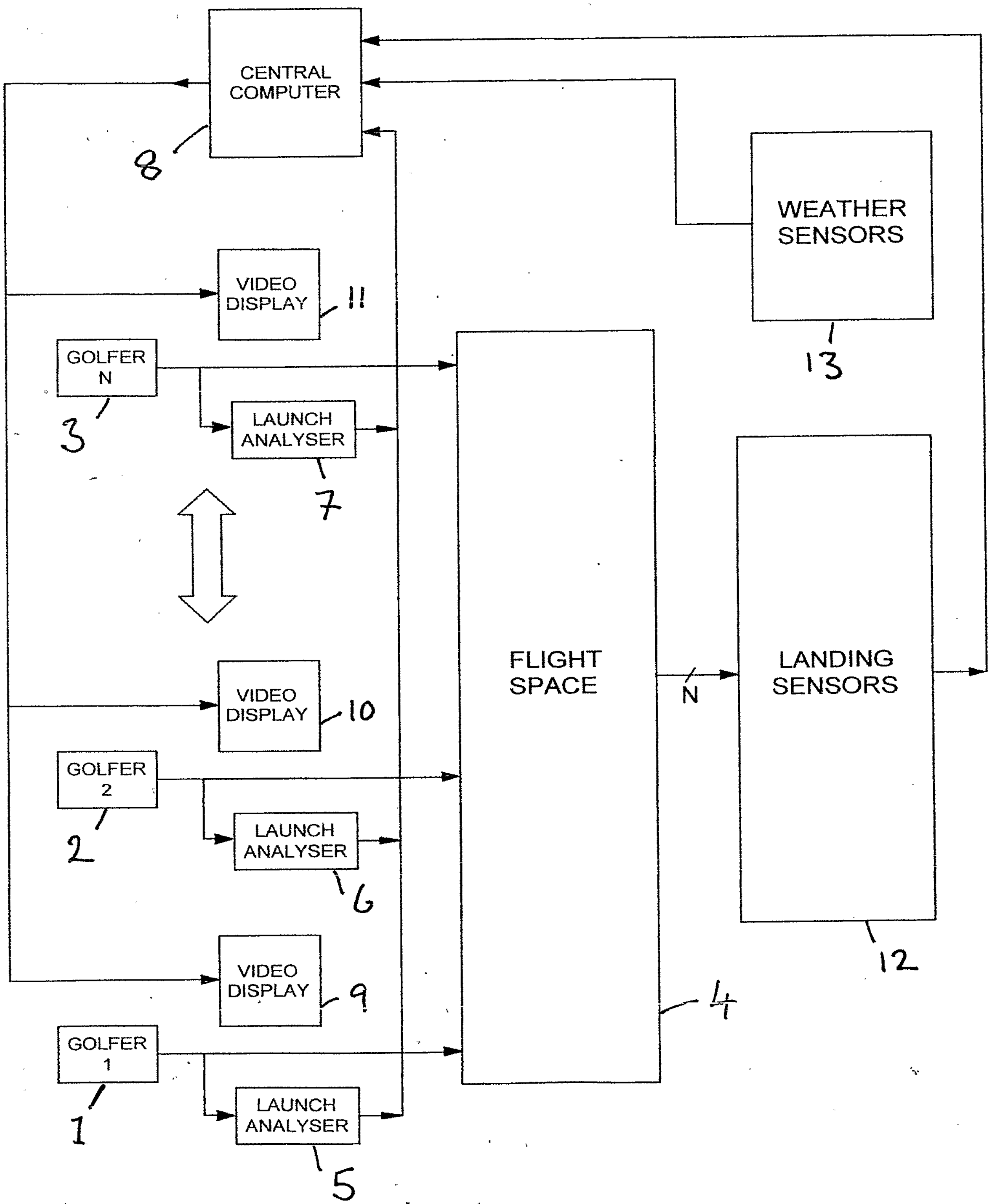
CENTRAL COMPUTER
8
WEATHER SENSORS
13
VIDEO DISPLAY
11
GOLFER N
3
LAUNCH ANALYSER
7
FLIGHT SPACE
N
LANDING SENSORS
VIDEO DISPLAY
10
GOLFER 2
2
LAUNCH ANALYSER
6
12
VIDEO DISPLAY
9
4
GOLFER 1
1
LAUNCH ANALYSER
5

FIG. 1

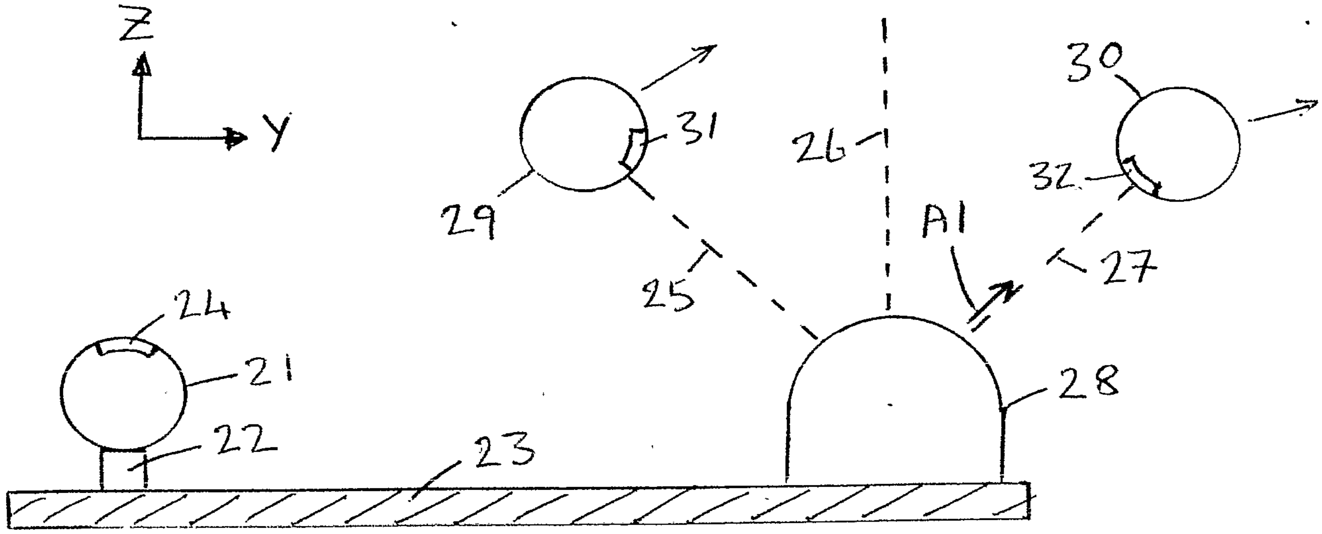

FIG. 2

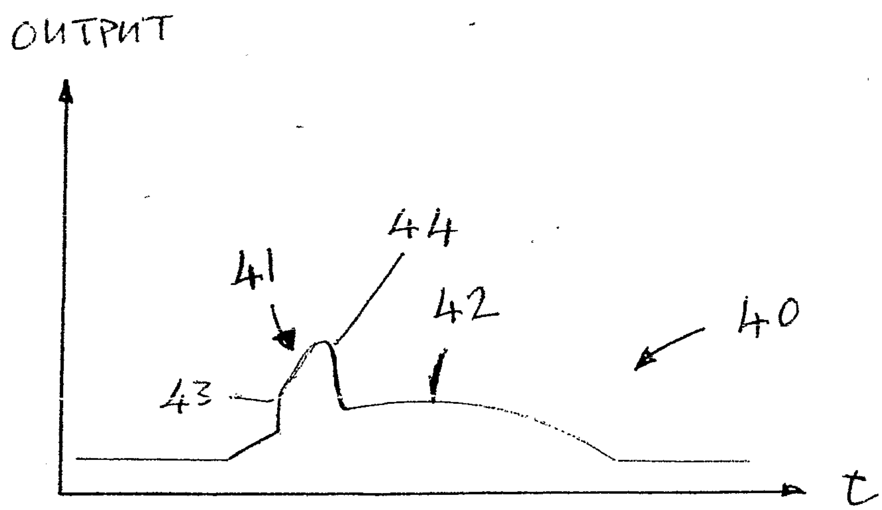

FIG. 3

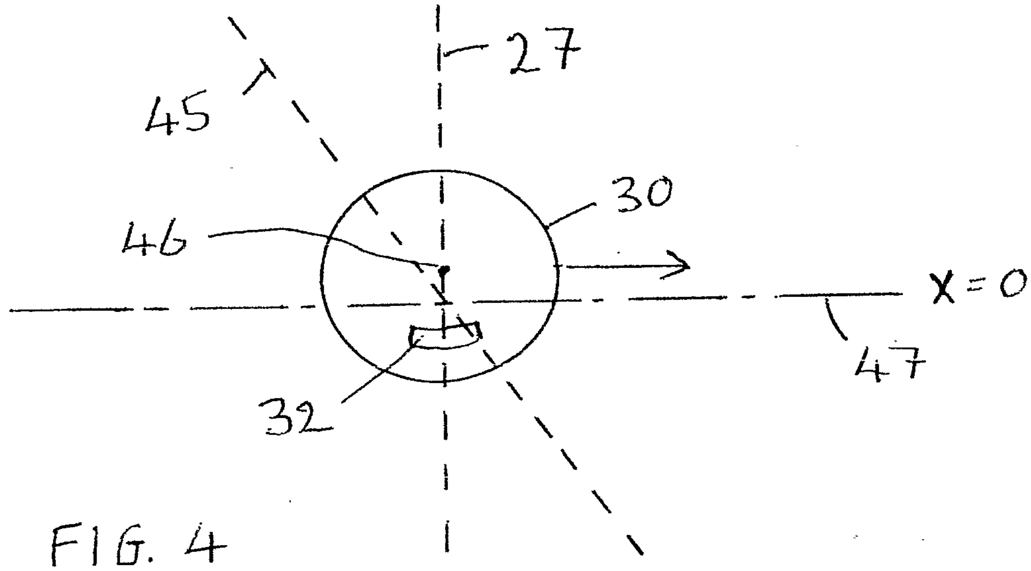

FIG. 4

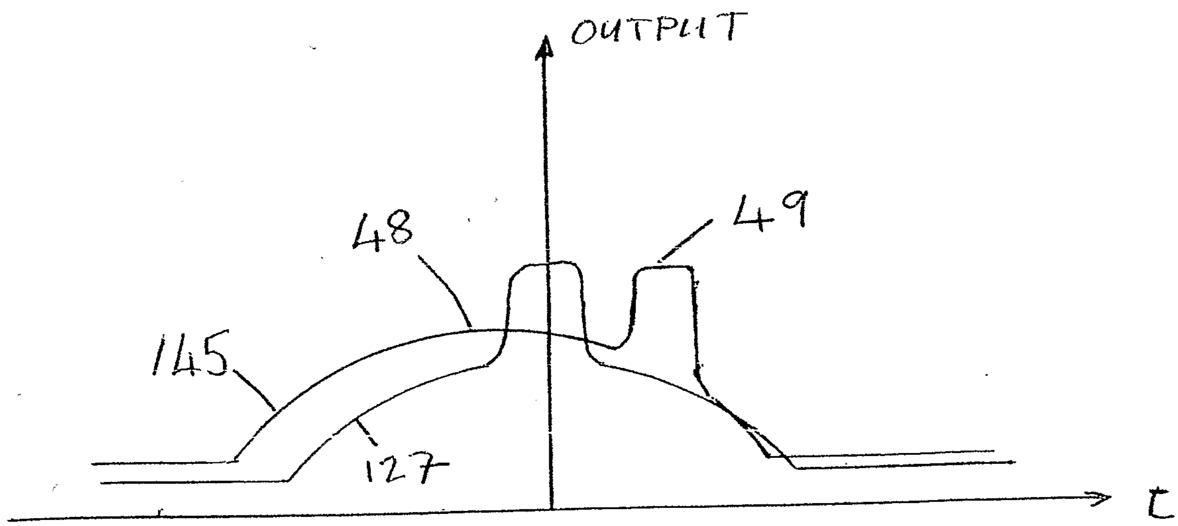

FIG. 5

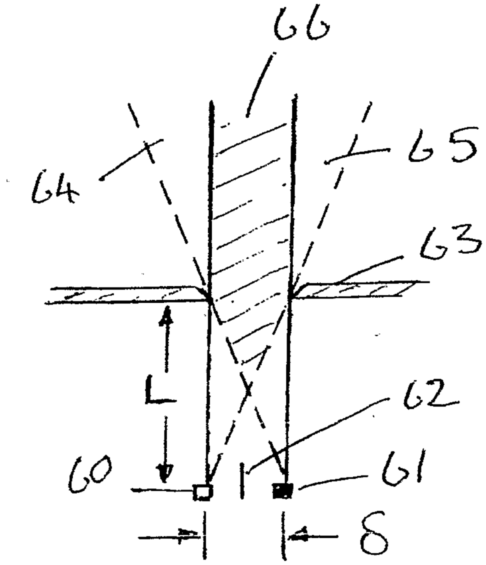

FIG. 6(a)

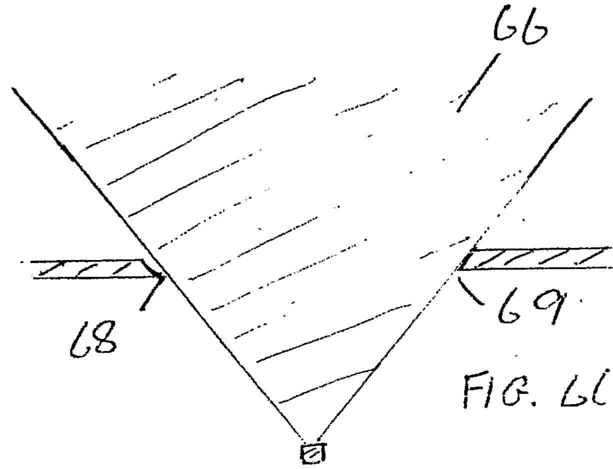

FIG. 6(b)

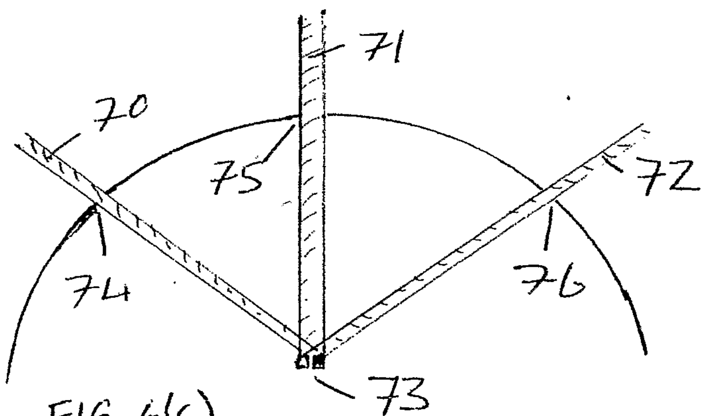

FIG. 6(c)

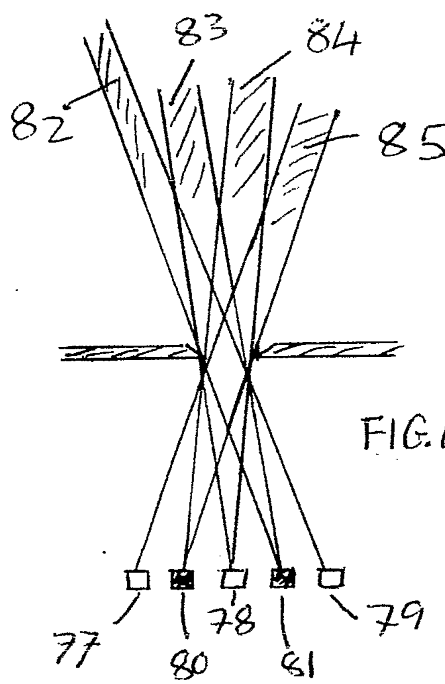

FIG. 6(d)

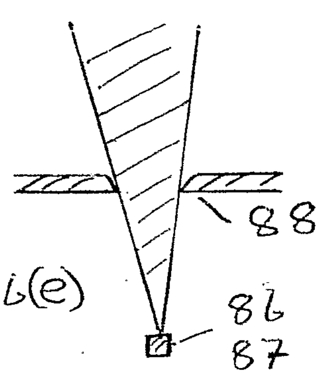

FIG. 6(e)

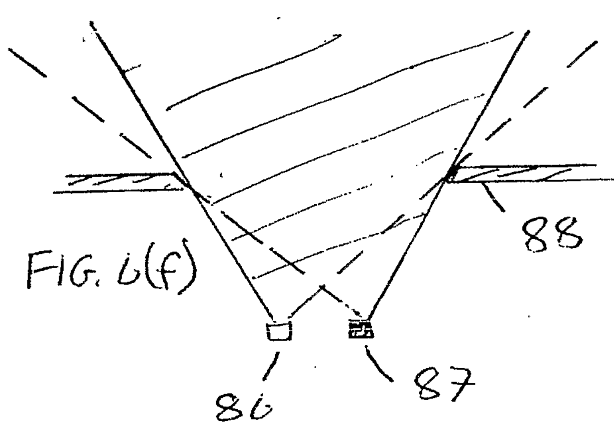

FIG. 6(f)

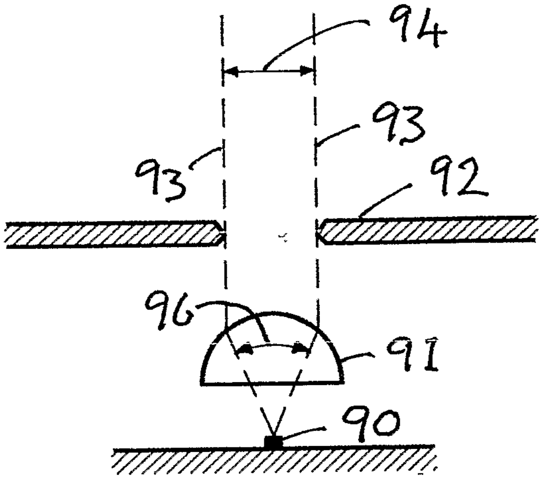

FIG. 7(a)

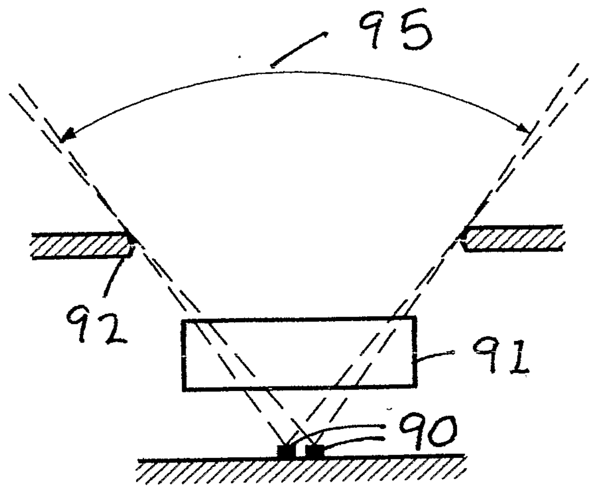

FIG. 7(b)

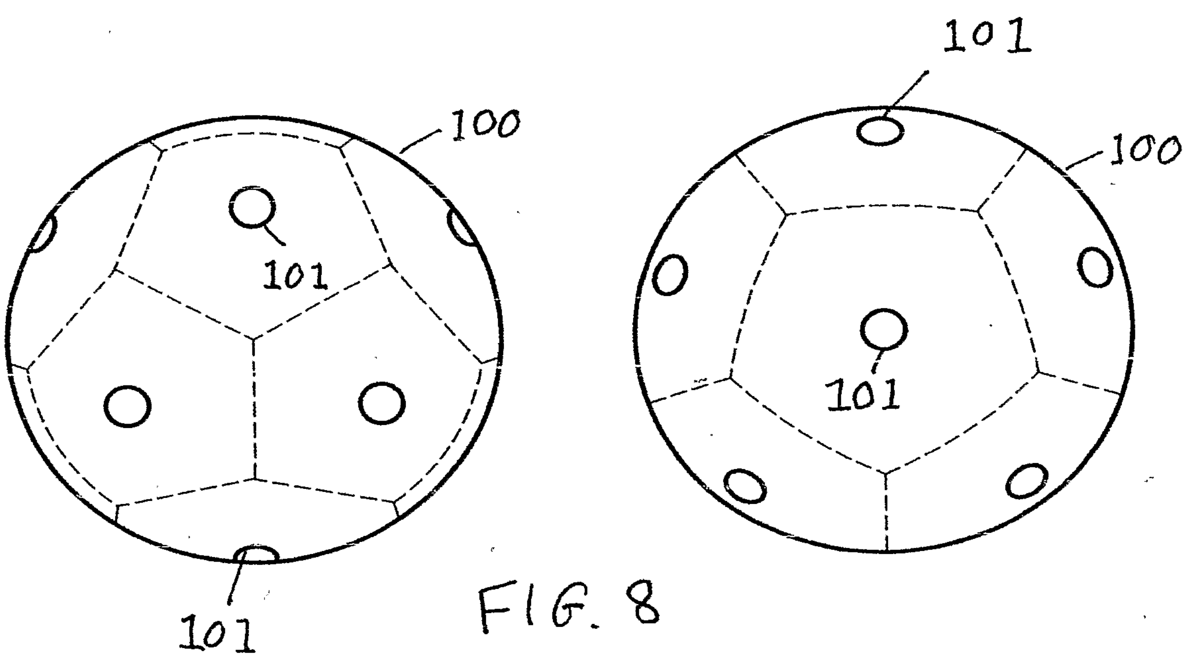

FIG. 8

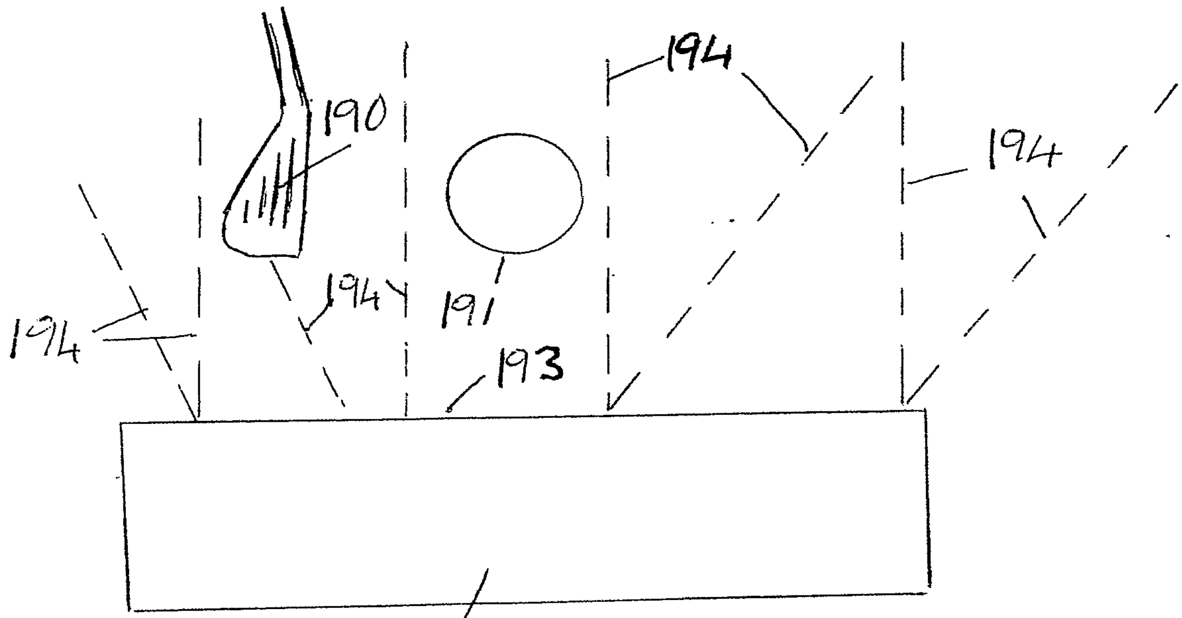

FIG. 9

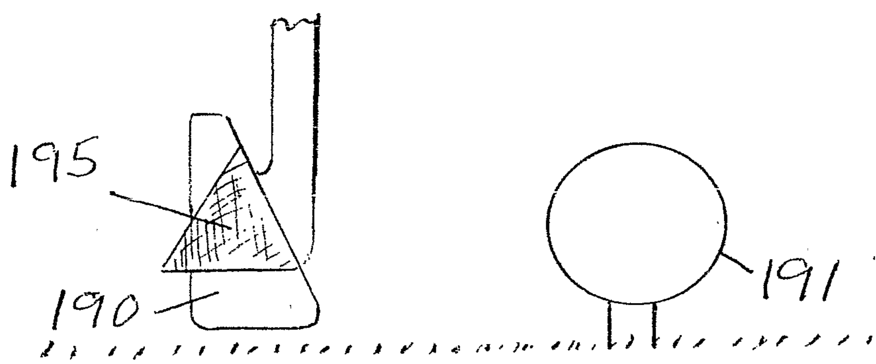

FIG. 10

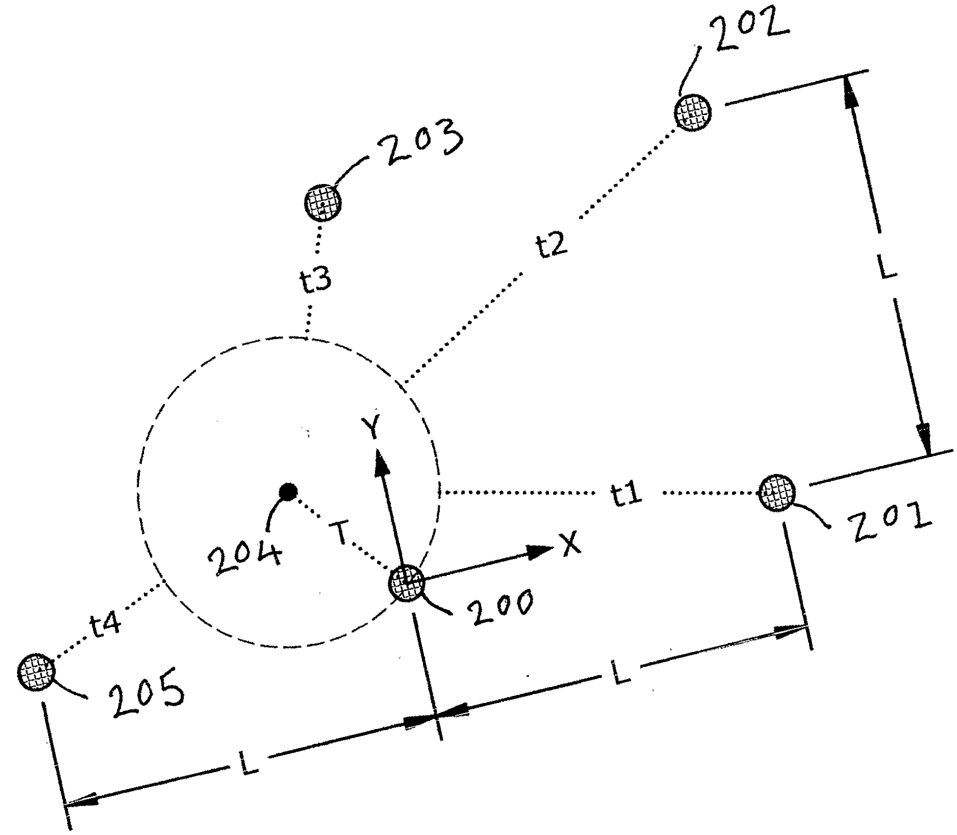

FIG. 11